BICONICAL TAPER COAXIAL COUPLER FILTER

Indexing terms: Optics, Optical filters, Optical connectors and couplers

The wavelength-dependent transmission characteristics of biconical tapers fabricated from single-mode fibres of depressed cladding are examined. The wavelength response is found to be oscillatory with large modulation depths. We describe here a simple fabrication technique which produces narrow passband filters of low loss and high extinction ratio (>30 dB).

Introduction: We have recently described the biconical tapered coaxial coupler as a solution to the phase matching problem of the coaxially coupled rod and tube waveguides[1] at a desirable operating wavelength.[2] This technique enables us to fabricate coaxial couplers from slightly depressed cladding communication fibres, i.e. from heavily mismatched coaxial waveguides.

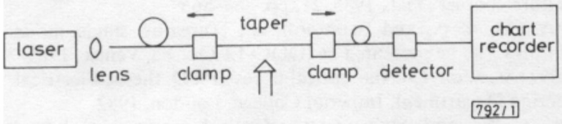

Fig. 1 *Experimental set-up for taper filter fabrication*

For certain applications it would be desirable to propagate only certain wavelengths through the fibre while heavily attenuating the undesirable wavelengths. Such filtering behaviour is not observed in single-mode fibres, which support a broad wavelength continuum. We use the tapering technique to modify the wavelength transmission of the fibres. The wavelength response of the biconical tapered coaxial couplers is presented in this letter.

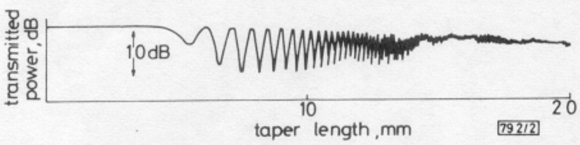

Fig. 2 *Output power during tapering of a slightly depressed single-mode optical fibre*

Fabrication and results: A strand of slightly depressed cladding single-mode fibre (GEC Optical Fibres) is placed on a motorised fabrication jig (Fig. 1). The acrylate coating layer was removed from the region to be tapered. Laser light was launched into the fibre and the output power was displayed on a chart recorder. An oxybutane flame was used locally to heat the fibre for the taper fabrication.

Fig. 2 shows a typical trace of power detected in the core, while tapering takes place. The deep oscillation minima have been explained[2,3] as being due to coaxial coupling between the fibre core and secondary fibre cladding tube waveguides. The core and cladding waveguide fundamental modes are coupled in the taper region, and significant power exchange takes place along its length. Light remaining in the tube waveguide at the taper output is fast attenuated and occurs at the minima of the oscillations in Fig. 2. The coupling coefficient[4] and mode phase mismatch are both wavelength-dependent, and this is used in this work for filter fabrication.

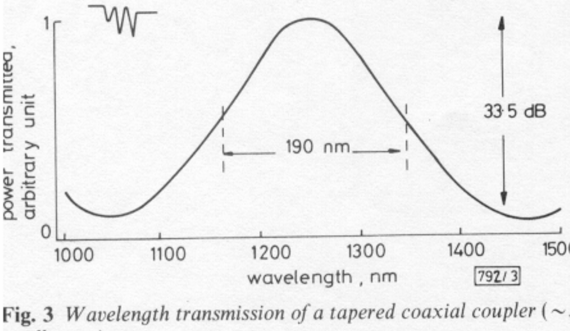

Fig. 3 *Wavelength transmission of a tapered coaxial coupler (~3 power oscillations)*

We have fabricated a number of tapers using the same flame size but with a variety of taper lengths. The tapering process was stopped when complete power oscillations were observed. The wavelength response of these tapers was observed with a white light source monochromator and lock-in amplifier system. We have found that the extinction ratio results measured are less accurate with this experimental set-up compared with those obtained when a laser source is used.

Fig. 3 shows the wavelength-dependent power transmission of such a taper and the inset shows the chart recorder trace during the fabrication of this taper, using the experimental set-up of Fig. 1 and a laser at $\lambda = 1{\cdot}52\ \mu m$. In this case the passband is 190 nm and oscillatory. The oscillation is of at least 33 dB modulation depth.

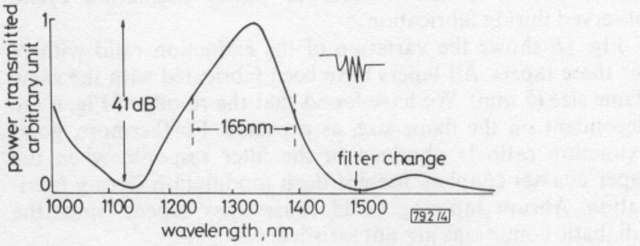

Fig. 4 *Wavelength transmission of a taper coaxial coupler (~4 power oscillations)*

Fig. 4 shows another wavelength-dependent power transmission, the taper pulled at a longer length (inset shows four power oscillations), and the passband is now 165 nm wide and 41 dB modulation. Finally, a taper extended to the 20th oscillation is shown in Fig. 5, having a passband of 35 nm with >17 dB modulation. The narrowing of the passband with the length of the taper is expected, since the longer tapers are essentially multiple-beat-length couplers. It is clear that such tapers present filtering behaviour, having an excellent extinction ratio.

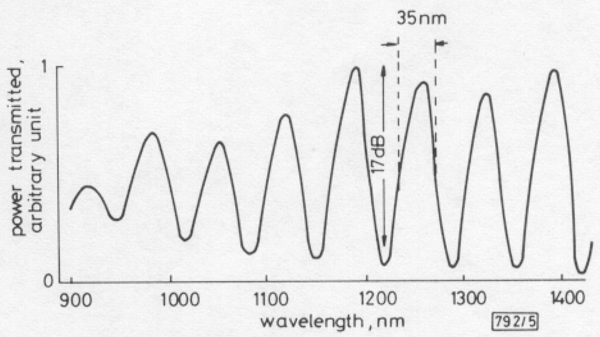

Fig. 5 *Wavelength transmission of a taper coaxial coupler (~20 power oscillations)*

We have fabricated filters having a passband of 20 nm when the taper has been elongated during fabrication to 40 power oscillations. Therefore, although very narrow passband

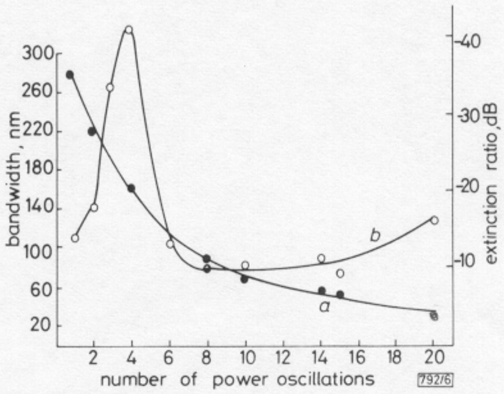

Fig. 6

a 3 dB passband of wavelength filters against number of power oscillations during fabrication
b Extinction ratio of filters against number of power oscillations

filters are possible, we observe that the extinction ratio decreases with the taper bandwidth as the number of power oscillations increases. We believe, however, that this effect is not a limitation, and could be reversed by careful choice of flame size and shape.

Fig. 6*a* shows a graph of the filter bandwidth against the number of power oscillations during the fabrication of the coaxial coupler ($\lambda = 1{\cdot}52\ \mu$m, 1 oscillation = 2 beat lengths). An approximate empirical equation described this curve is given by

$$B = N^{-3/4}$$

where B is the wavelength separation of the 3 dB power points and N is the number of power oscillation cycles observed during fabrication.

Fig. 6*b* shows the variation of the extinction ratio with N for these tapers. All tapers have been fabricated with the same flame size (5 mm). We have found that the results of Fig. 6 are dependent on the flame size, as expected. Furthermore, good extinction ratio is obtained in the filter response when the taper coaxial couplers present deep modulation during fabrication. Abrupt tapering could cause lossy tapers[5] since the adiabatic conditions are not satisfied.

In conclusion, we have presented the wavelength response for tapered coaxial couplers, fabricated from single-mode communication fibres with a slightly depressed cladding. This indicates that it is possible to fabricate all-fibre filters of high extinction ratio and low loss by a simple tapering process.

Acknowledgments: We would like to thank GEC Optical Fibres for providing the fibres for the experiments and Mr. R. Dewan and R. Marwaha for their expert assistance.

A. C. BOUCOUVALAS
G. GEORGIOU

GEC Research Limited
Hirst Research Centre
East Lane, Wembley, Middx. HA9 7PP, United Kingdom

30th August 1985

References

1 COZENS, J. R., BOUCOUVALAS, A. C., AL-ASSAM, A., LEE, M. J., and MORRIS, D. G.: 'Optical coupling in coaxial fibres', *Electron. Lett.*, 1982, **18**, pp. 679–681
2 BOUCOUVALAS, A. C., and GEORGIOU, G.: 'Biconical taper coaxial optical fibre coupler', *ibid.*, 1985, **21**, pp. 864–865
3 BOUCOUVALAS, A. C., and GEORGIOU, G.: 'Tapering single mode optical fibres'. To be presented at IOOC–ECOC '85, Venice, 1985
4 BOUCOUVALAS, A. C.: 'Coaxial optical fibres'. Ph.D. thesis, Electrical Engineering Department, Imperial College, London, 1982
5 SNYDER, A. W., and LOVE, J. D.: 'Optical waveguide theory' (Chapman & Hall, London, 1983), p. 410